Earth Observing System (EOS)
Microwave Limb Sounder (MLS)

EOS MLS Measurements and Science Objectives

- with emphasis on the upper troposphere and lower stratosphere

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MLS web site:
http://mls.jpl.nasa.gov

invited paper for COSPAR 2002
Session on Climate Change Processes in the Stratosphere and at the Tropopause
Houston, 17 October 2002

Outline of talk

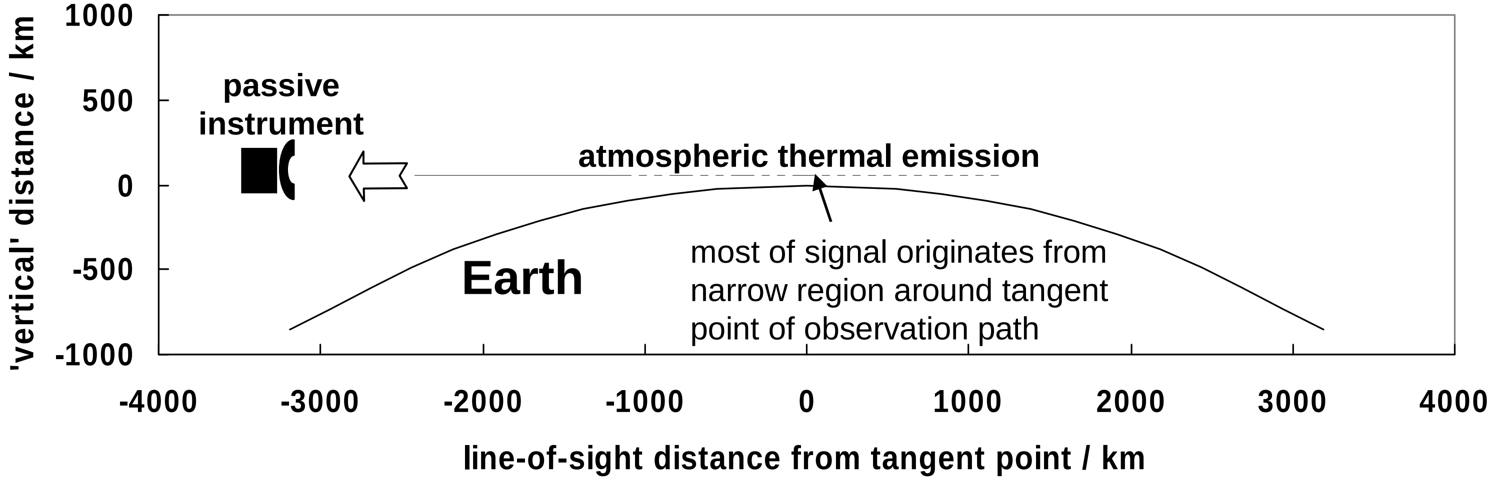
- Brief description of MLS technique

- Some lower stratospheric and upper tropospheric results from UARS MLS

- EOS MLS measurements and science objectives
  - with emphasis on the upper troposphere and lower stratosphere

Microwave Limb Sounding

- A technique for remote sensing Earth's atmosphere
- Measures atmospheric thermal emission spectra at mm/submm wavelengths as the instrument field-of-view is scanned through the limb from above



Some features of Microwave Limb Sounding

- Can ‘see through’ cirrus and dense aerosol

- Many chemical species can be measured
  - as well as temperature, pressure and cloud ice

- Upper tropospheric water vapor, cloud ice, and temperature can be measured simultaneously

- Measurements can be made at all times of day and night

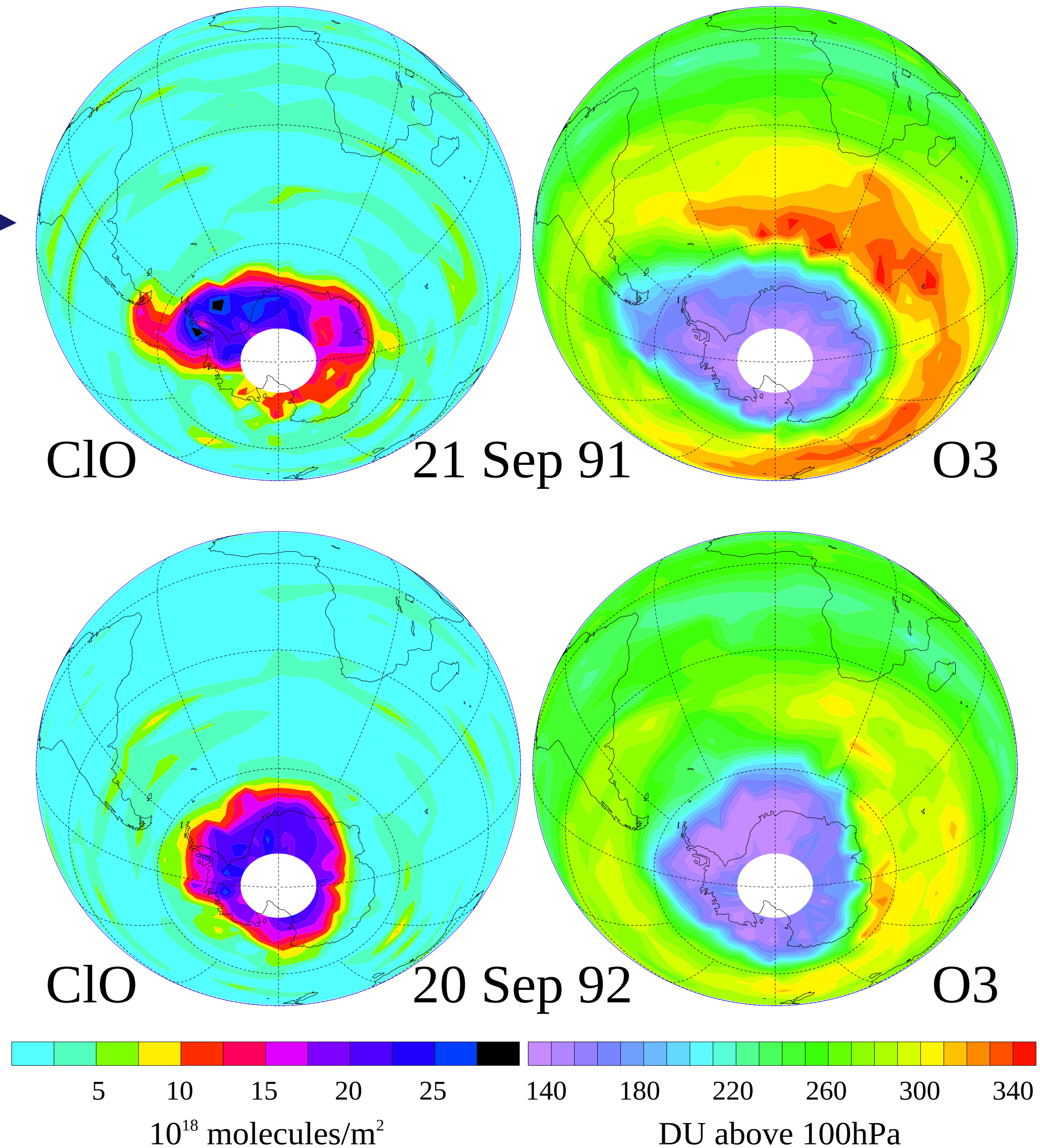
The MLS Experiments

- **Upper Atmosphere Research Satellite (UARS) MLS**
  - Operational 1991-2000, but intermittent after ~1995
    - Designed for measurements in <u>middle & upper</u> stratosphere (design frozen before discovery of Antarctic ozone hole) and for 2-year operational lifetime
  - Primary science objective
    - Stratospheric ozone and chlorine chemistry
- **Earth Observing System (EOS) MLS**
  - Now being readied for launch on EOS Aura in 2004
    - Designed to include upper tropospheric & lower stratospheric measurements and for 6-year operational lifetime
  - Primary science objectives
    - Stratospheric (and some tropospheric) chemistry
    - Climatic issues involving upper tropospheric H_2O

UARS MLS Measurements of Stratospheric ClO and Ozone

(ClO is dominant form of chlorine that destroys ozone)

21 Sept 1991 measurements made 9 days after launch

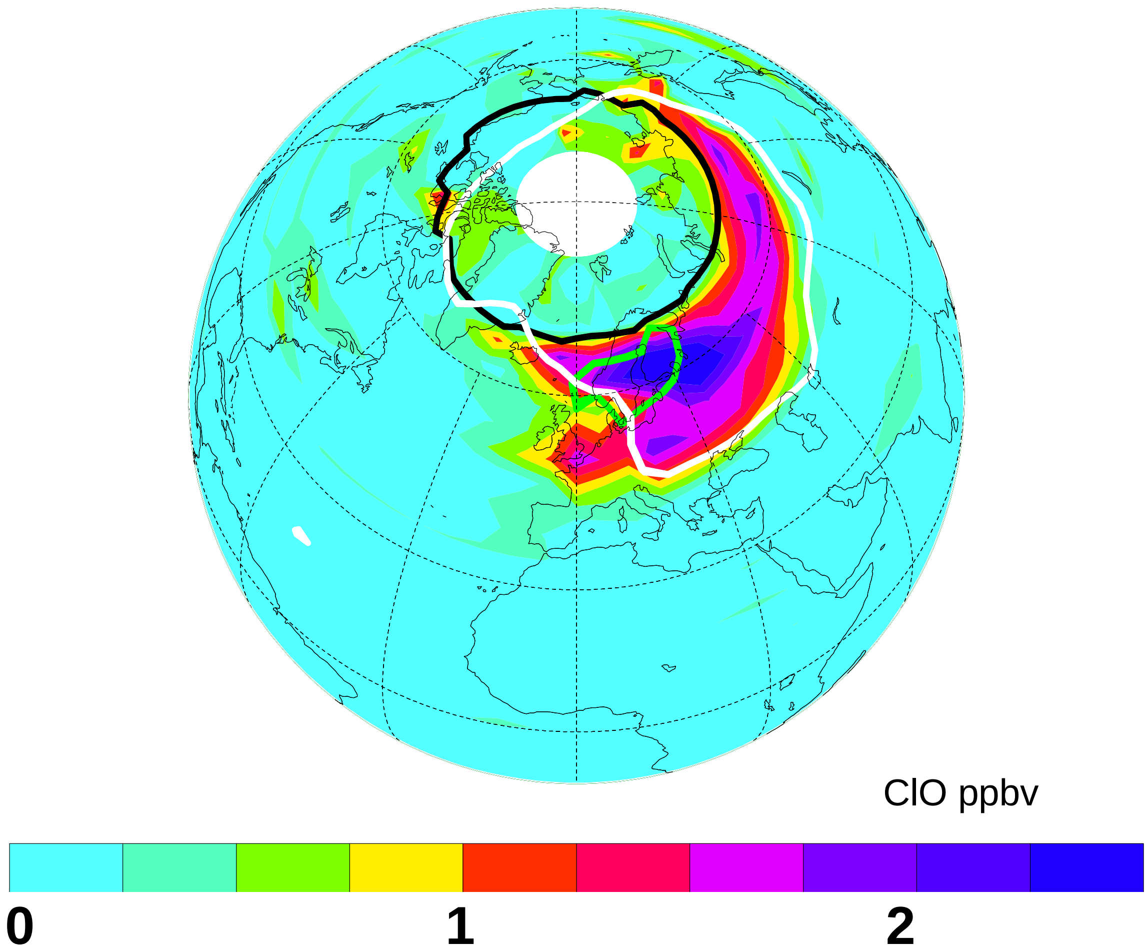


Waters et al., *Nature* 1993

UARS MLS Measurements of Enhanced ClO in Arctic Lower Stratosphere

Example of measurements on 11 Jan 1992 at ~20 km ht (465 K potential temperature)

white contour: potential vorticity at vortex edge
black contour: edge of daylight
green contour: 195 K temperature (at which PSCs form)



Comparable amounts of enhanced ClO occur in the Arctic and Antarctic - but Arctic enhancement does not remain as long as in the colder Antarctic

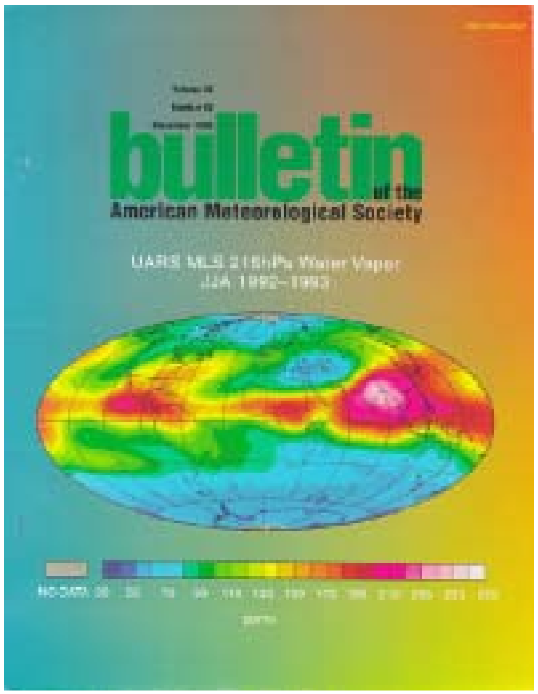
Arctic: 14 Feb 1993
Antarctic: 14 Aug 1992
Waters et al., *Nature* 1993

Upper Tropospheric Humidity (UTH)

unplanned MLS data product - but important for climate change research

Read et al., *JGR 106*, 32207 (2001) describe MLS UTH measurement & validation

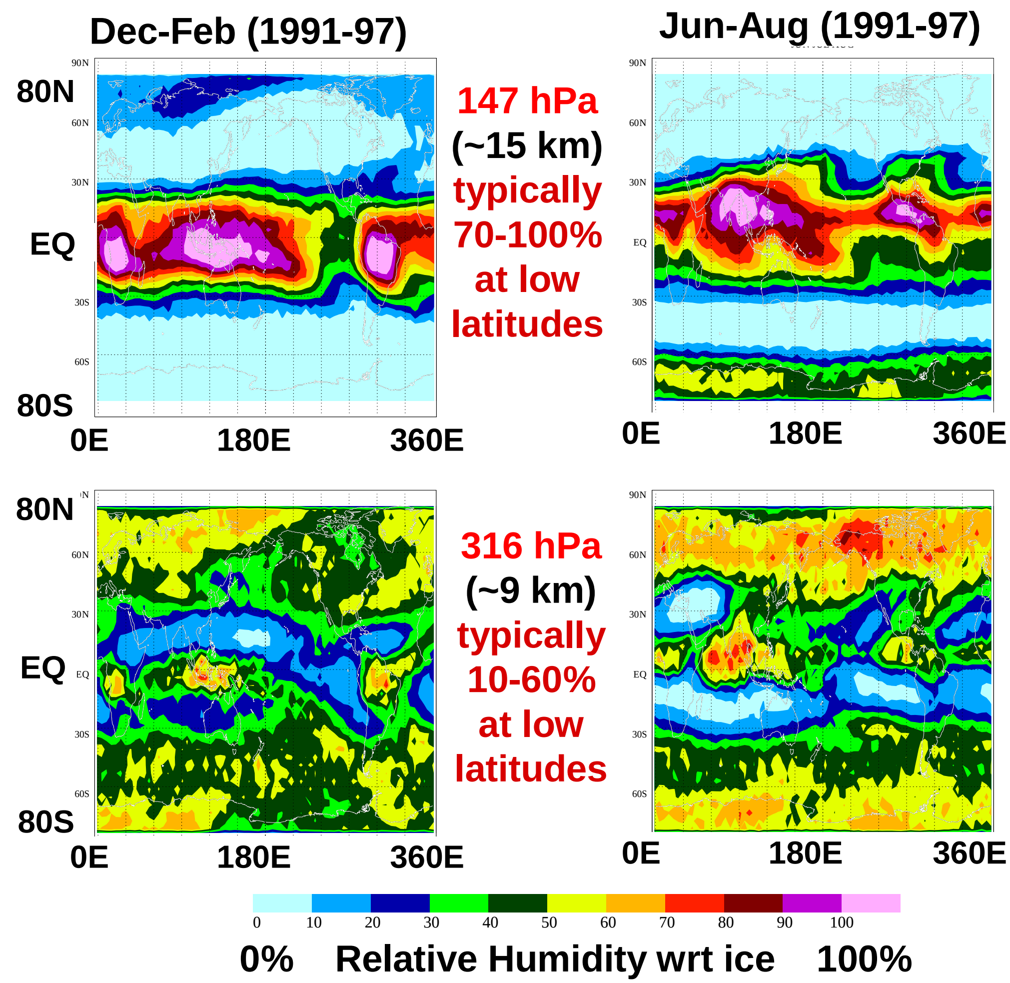
H_2O mixing ratio at 215 hPa



MLS has provided the first global UTH data set that includes measurements in the presence of ice clouds. Positive correlation is seen between 215 hPa H_2O and regions of deep convection

Read et al., *BAMS* 1995

Relative humidity (%) with respect to ice

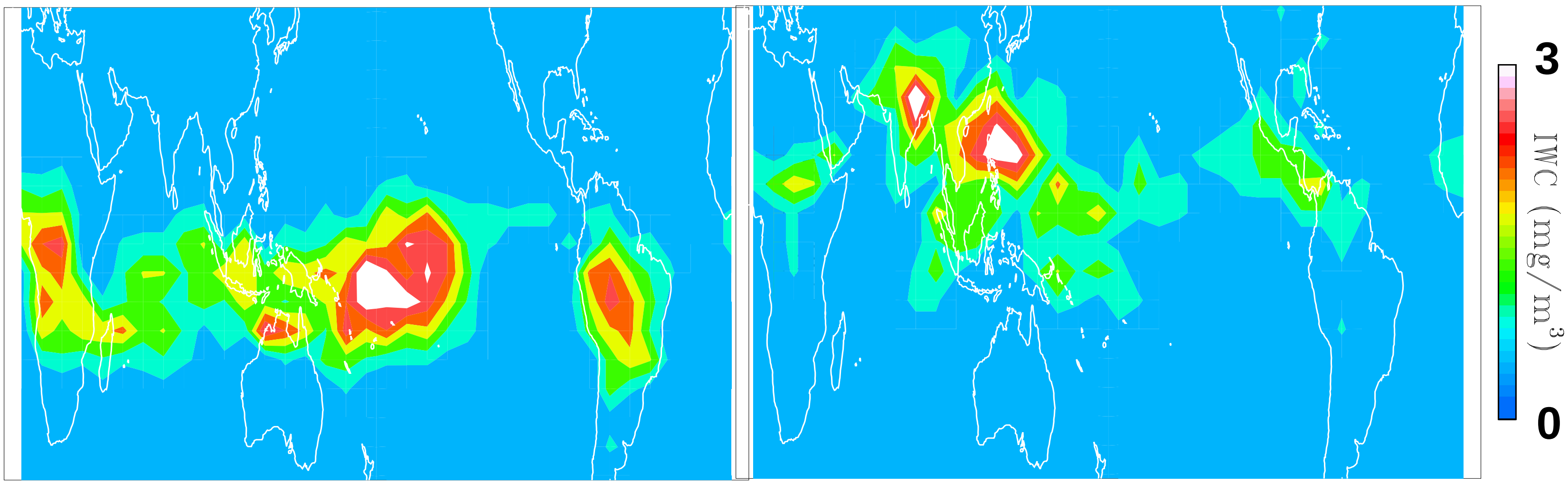


Read et al., *JGR* 2001

UARS MLS measurements of cloud ice at ~100 hPa (tropical tropopause)

this measurement is still a research topic

January - March 1992 **July - September 1992**



Colors give the average ice water content (IWC) in the MLS field of view when pointed at ~100 hPa

Improvements of EOS MLS over UARS MLS

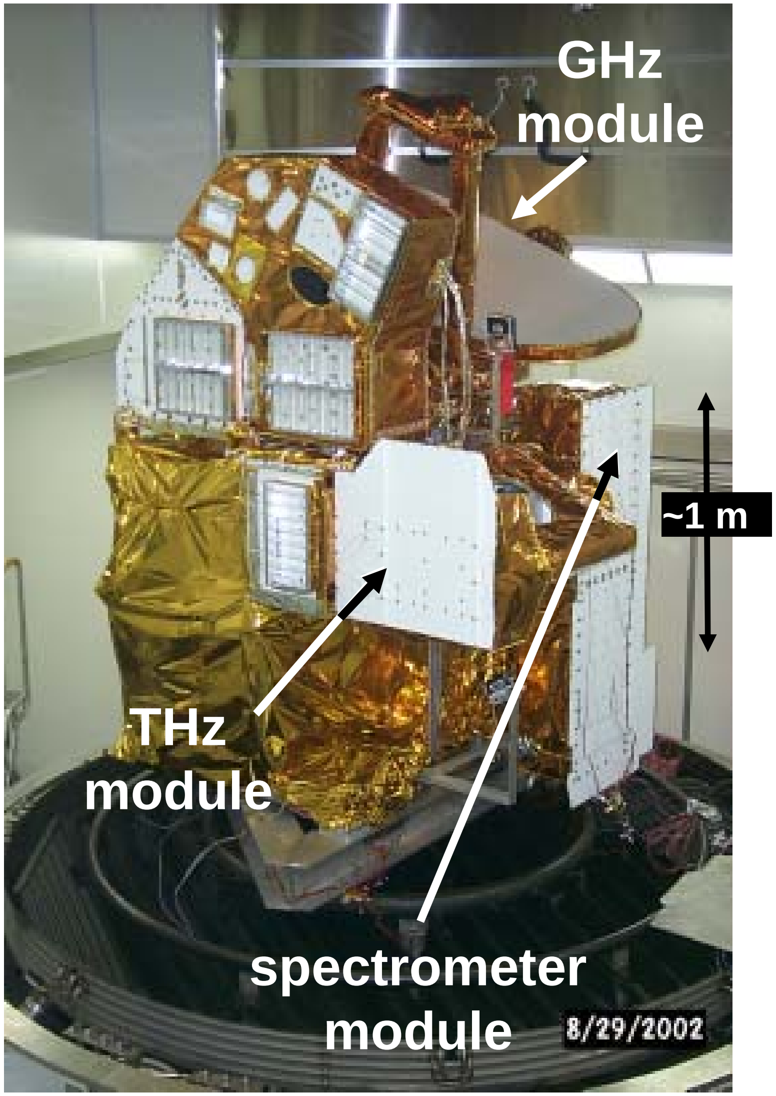
- **Designed for upper tropospheric measurements**
  - **H_2O, temperature, O_3, CO, cirrus ice, HCN, (CH_3CN also measured)**
- **Designed for more stratospheric measurements**
  - **OH, HO_2, H_2O, O_3, ClO, HCl, HOCl, BrO, HNO_3, N_2O, CO, HCN, temperature (CH_3CN and volcanic SO_2 also measured)**

  and for measurements in lower stratosphere
- **Better precision for most data; better spatial resolution**
  - **~20x better sensitivity for lower stratospheric O_3**
  - **~2-3 km vertical resolution for most data (~2x better than UARS MLS)**
  - **Useful upper troposphere H_2O measurements at ~1 km vertical resolution**
  - **Profile every ~165 km along the measurement track, vs ~500 km for UARS**
- **Better measurement geometry**
  - **Aura orbit gives EOS MLS ±82º latitude coverage *every day on each orbit* whereas UARS MLS alternated monthly between N and S high latitudes**
- **3x longer design lifetime**

The EOS MLS Instrument

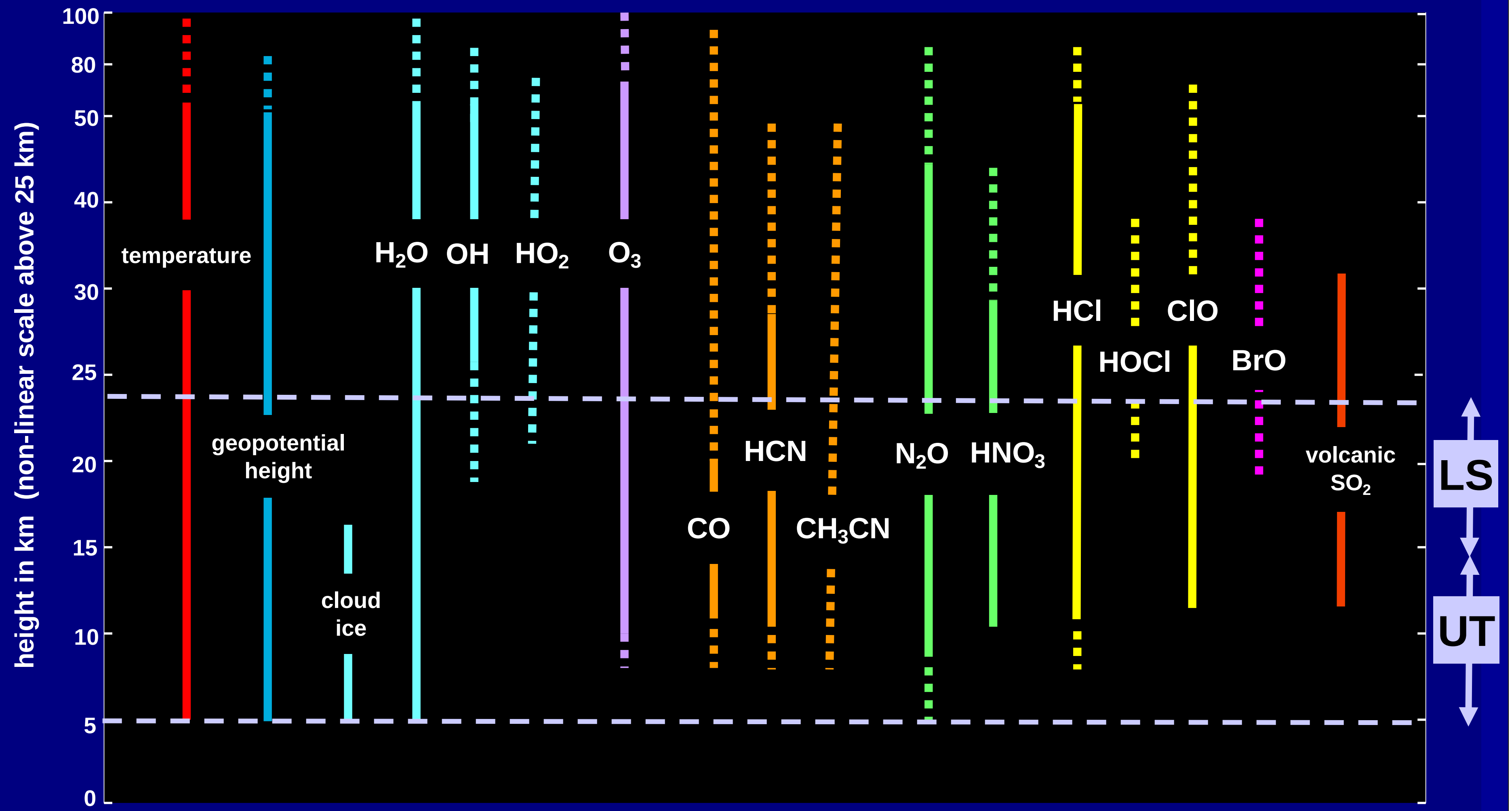
- **Has broadband radiometers operating in five mm/submm bands centered at**
  - **118 GHz (2.5 mm wavelength)** **primarily for temperature and pressure**
  - **190 GHz (1.6 mm wavelength)** **primarily for H_2O and HNO_3**
  - **240 GHz (1.3 mm wavelength)** **primarily for O_3 and CO**
  - **640 GHz (0.47 mm wavelength)** **primarily for HCl, ClO, BrO, HO_2, N_2O**
  - **2.5 THz (0.12 mm wavelength)** **primarily for OH**
- **Some overall characteristics**
  - **550 W full-up power consumption**
  - **450 kg total mass**
  - **100 kb/s data rate**

instrument at end of thermal-vacuum tests



EOS MLS Atmospheric Measurements

(dotted lines indicate averages)



Solid lines indicate useful precision for individual profiles or daily global maps.

Useful individual profiles for some species - e.g., HNO_3 and CO - may not be obtained at all latitudes due to variation in abundance with latitude.

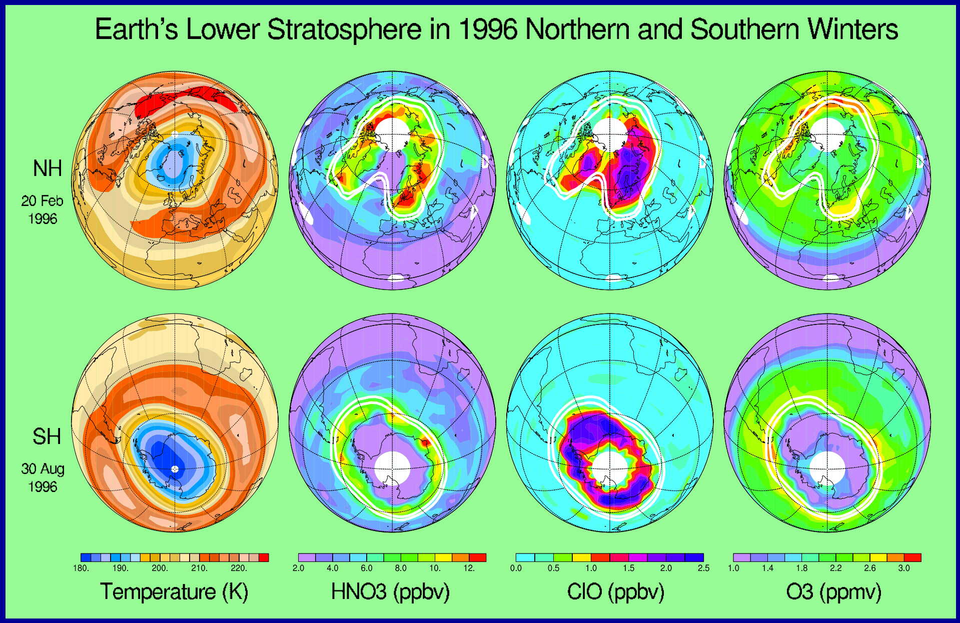
Dotted lines indicate that averages are expected to be needed for useful precision.

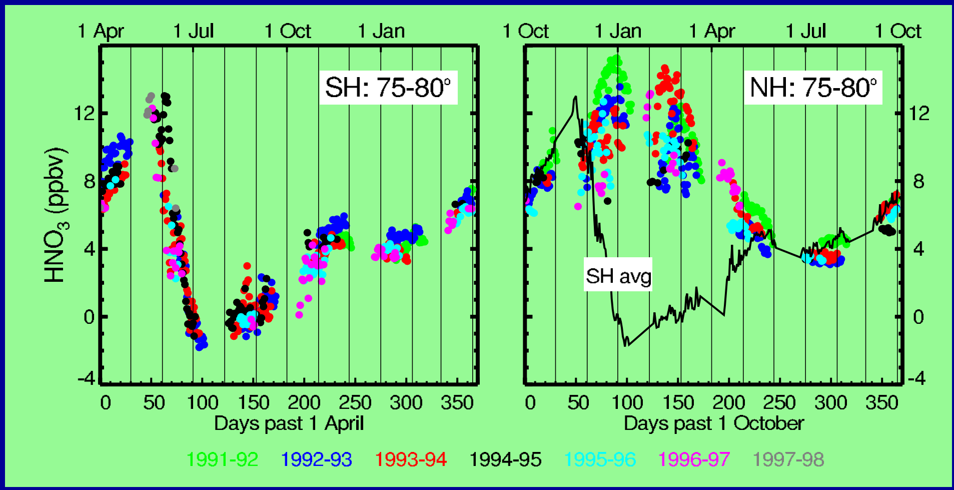
Expected precisions for all measurements are available at http://mls.jpl.nasa.gov

A Scientific Objective of EOS MLS
Determining if Stratospheric Ozone Chemistry is Recovering

- **Are stratospheric chlorine and ozone chemistry responding to regulations as expected?**
- **Will ozone recovery be delayed by climate changes?**
  - **cooling of lower stratosphere**
  - **increase in stratospheric H_2O**
  - **changes in circulation**
- **Will Arctic, due to changing climate, experience severe denitrification and increased ozone depletion?**
- **Do we adequately understand stratospheric chemistry and transport at all altitudes / latitudes?**
- **How will volcanoes affect recovery?**
- **MLS stratospheric measurements to address these questions:**
  - **HCl, ClO, O_3, HNO_3, H_2O, N_2O, OH, HO_2, BrO, HOCl, T, SO_2**

UARS MLS HNO_3, ClO, and O_3

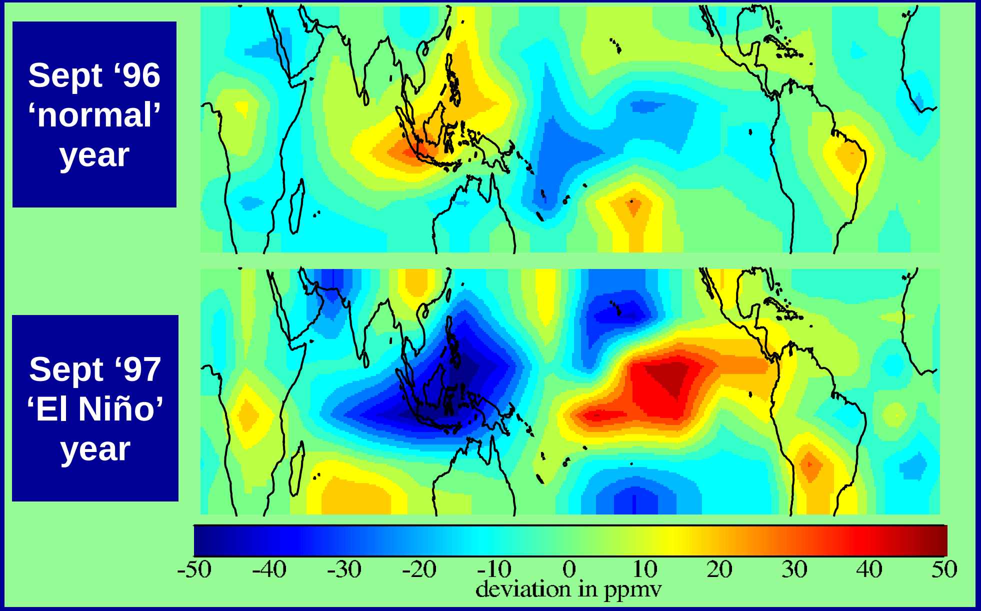




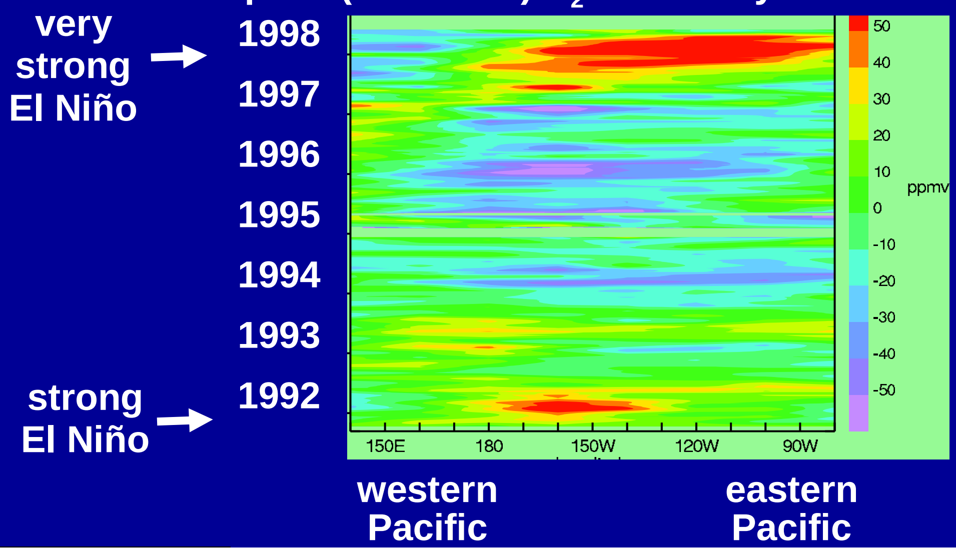
A Scientific Objective of EOS MLS
Improving Knowledge of Processes Affecting Climate Variability

- How do feedback mechanisms involving upper tropospheric H_2O affect climate variability?
- What are the atmospheric processes that control upper tropospheric H_2O abundances?
- How do sea surface temperature variations affect upper trop H_2O (and thus climate)?
- How do lower stratospheric H_2O and O_3, and possibly Arctic vortex variations, affect climate?
- MLS upper troposphere / lower stratosphere measurements to address these questions:
  - H_2O, cirrus ice, temperature, O_3, and 'tracers' CO, N_2O

UARS MLS Upper Trop (215 hPa) H_2O and El Niño



tropical (5° N - 5° S) H_2O anomaly at 215 hPa

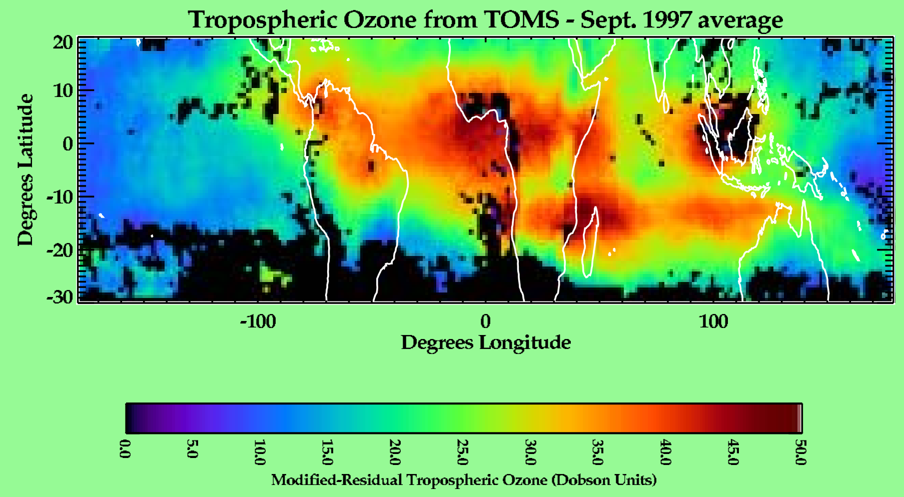


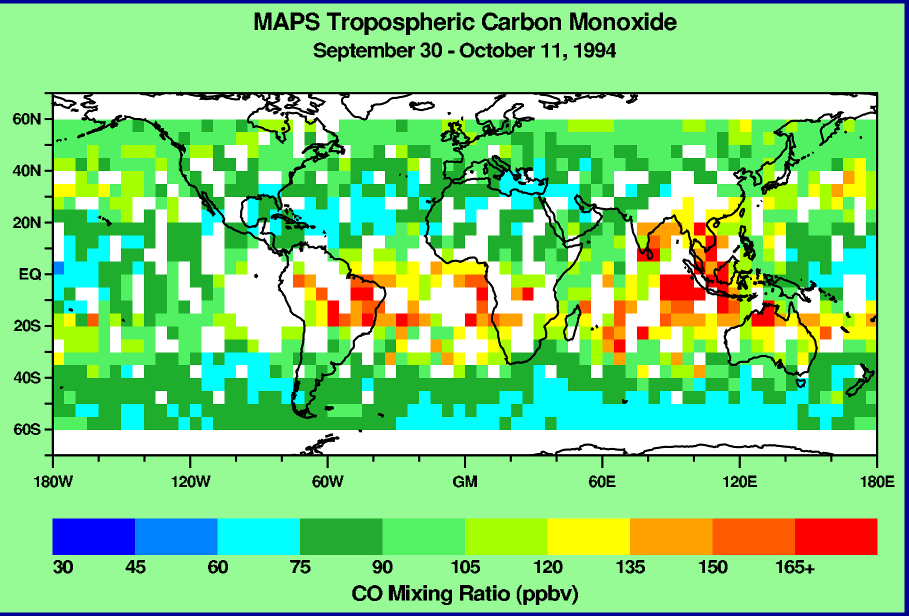
A Scientific Objective of EOS MLS

Helping Understand Ozone and Pollution in the Upper Trop

- What is the global distribution of ozone in the upper troposphere?
- What are the dominant sources of upper tropospheric ozone?
- How is regional pollution related to global upper tropospheric pollution?
- How might expected increases in upper tropospheric ozone affect global air quality?
- MLS upper trop measurements to address these questions:
  - O_3, CO, HCN, CH_3CN, and possibly H_2O and N_2O as tracers to identify air of stratospheric origin
- Difference between stratospheric O_3 column from MLS and total O_3 column from OMI (on Aura) will give total tropospheric O_3 column

TOMS residual tropospheric Ozone
MAPS tropospheric CO





Example of an upper trop / lower strat (UT/LS) science investigation to be pursued with EOS MLS data

Helping understand the cause of stratospheric aridity

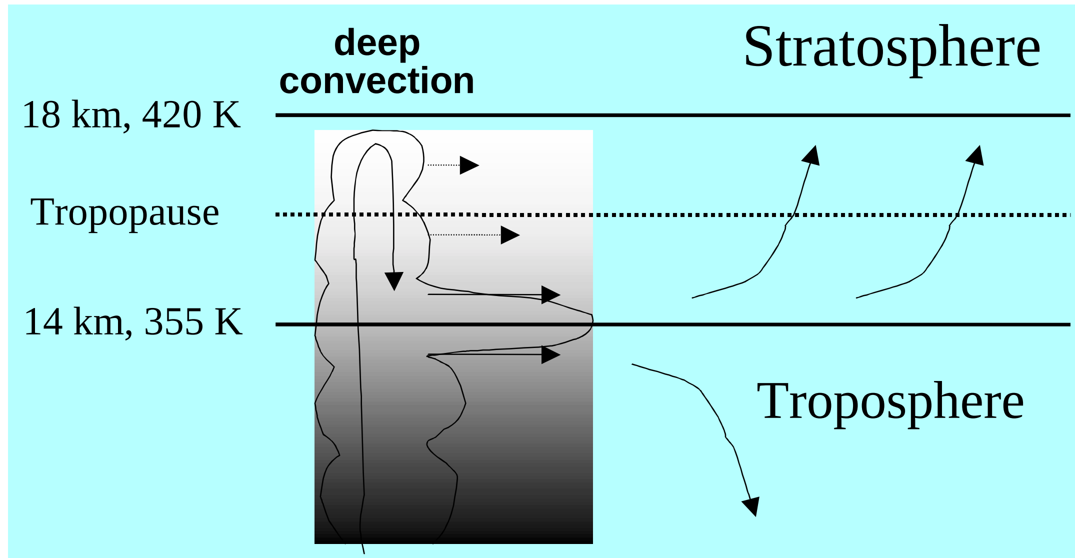
- **A current research objective is to understand how tropospheric air is dehydrated in the tropical tropopause layer (TTL)**

- **This is needed, for example, to improve understanding of how climate change might affect ozone recovery - by possibly changing the amount of stratospheric H_2O**

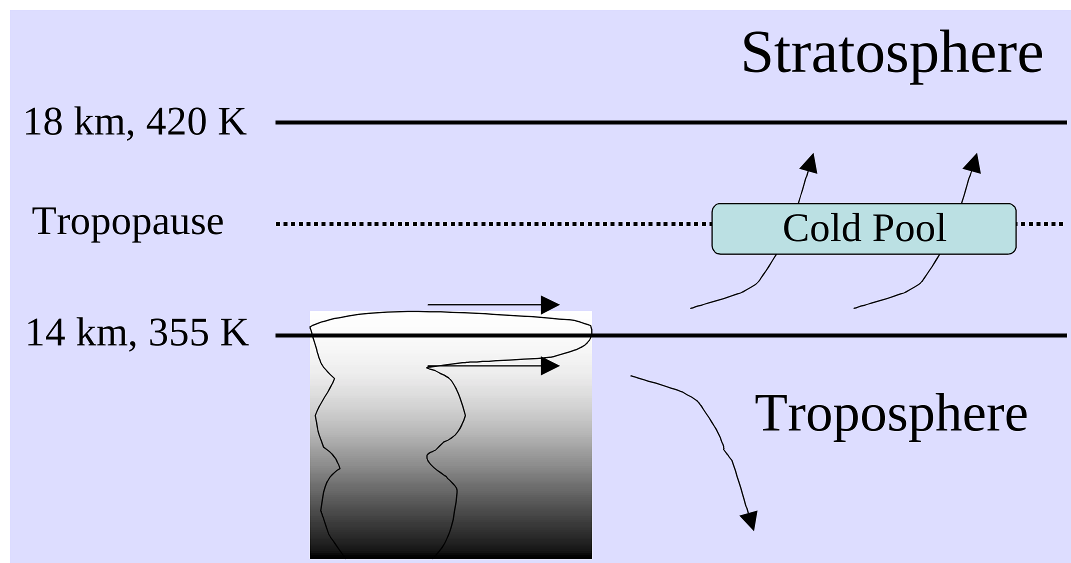
- **Following charts summarize two leading hypotheses, and how MLS data can help distinguish between them**

Hypotheses for the Cause of Stratospheric Aridity

Convective Dehydration
Sherwood and Dessler
GRL 2000



Cold Trap Dehydration
Holton and Gettelman
GRL 2001



Using EOS MLS Measurements to Distinguish between the Hypotheses

MLS measurement	Convective Dehydration Hypothesis	Cold Trap Dehydration Hypothesis
TTL high-altitude cloud ice, indicating convective overshoots	Requires ~0.5% of tropics to have overshoots†	No overshoots needed
H_2O distribution in the TTL	Should see very low H_2O in vicinity of and downstream from overshoots	Should see low H_2O downstream from the cold trap
Evolution of H_2O and O_3 features in the TTL	Should see evidence of significant vertical transport	Should be able to explain by horizontal transport
H_2O and O_3 correlation in the TTL	Positive correlation expected (low O_3 brought up by the overshooting convection that causes dehydration)††	No correlation expected

† Sherwood, SPARC Newsletter 17, 2002

†† Evidence seen in aircraft data: Sherwood and Dessler, GRL 27, 2000

Approach for distinguishing between the hypotheses

- Use cloud detection to characterize the frequency and distribution of convective overshoots (required by convective hypothesis)

- Produce H_2O maps in the TTL and use back trajectories to follow history of arid features & establish if there is correlation between

    1. lowest H_2O and convective overshoots (convective hypothesis)

  or

    2. lowest H_2O and lowest TTL temperatures (cold trap hypothesis)

- Study evolution of H_2O and O_3 features to see if there is evidence of input from vertical transport (required by convective hypothesis)

- Study H_2O/O_3 correlations - using N_2O and other tracers for separating tropospheric and stratospheric air - to determine if low H_2O came from overshooting deep convection

- Collaborate with scientists from other Aura (and other satellite) instruments - and with scientists doing aircraft measurements - to determine if wider suite of measurements and spatial resolutions give consistent picture

Summary

- **Microwave limb sounding provides some unique capabilities for study of the UT/LS**
- **Although UARS MLS was <u>not</u> designed for UT/LS measurements, it produced some important results for this region**
- **EOS MLS <u>is</u> designed for UT/LS measurements and will provide much improvement over UARS MLS for studying this region of the atmosphere**
- **The MLS team - as on UARS - looks forward to working with colleagues throughout the scientific community for using these and other measurements to better understand our atmosphere**